



Forest Biomass Availability and Utilization Potential in Sweden: A Review

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Abstract

In recent years, there has been a growing interest in many parts of the world for more effective biomass utilization due to legislative and public interest in sustainable development. Whilst much of the effort has been on energy generation from biomass, there is considerable interest on biomass availability and utilization for other end uses. With about 1% of the world's commercial forest areas, Sweden provides about 10% of the sawnwood, and pulp and paper that is traded on the global market. The Swedish agricultural sector also contributes to biomass availability, not only by production of sustainable food crops, but also by utilizing side streams and underutilized land for biomaterial purposes. To meet the challenges that climate change presents, there has to be a shift to sustainable biomass production and increased interest in promoting a circular bioeconomy. This review presents a systematic assessment on the availability of biomass and its utilization potential in Sweden. The review also focuses on biomass production and trade in the Swedish forest industry. In addition, the environmental impact of biomass utilization is discussed.

Graphic Abstract



Keywords Biomass · Environmental impact · Pulp and paper · Sawnwood · Sweden

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Statement of Novelty

There has been a number of literature studies on biomass availability with regard to bioenergy potential. This work comes in a series of studies conducted to explore the potentials of Swedish forest biomass in promoting a sustainable bioeconomy. However, the authors are not aware of any paper that specifically addresses forest biomass for non-energy utilization in Sweden. The novelty of this paper is that it presents an assessment on biomass availability and

utilization by the Swedish forest products industries, including biorefineries within the Swedish context.

Introduction

Biomass utilization has increased significantly in Sweden over the last few decades. Although forest resources and agricultural crops are the main biomass categories available in Sweden, a small percentage including logging residues and energy crops are directed towards energy generation. More than half the land area of Sweden, about 57% or 23 million hectares is covered by forests, making forest biomass the likely source for any substantial increase in renewable energy use and sustainable production. Whilst Sweden only has 1% of the total global forest cover, it accounts for more than 10% of the global forest industry business, which includes sawn timber, and pulp and paper products. It is estimated that available wood will drop from 2020 to 2030 in Sweden, but a major swing in markets supplied would occur with high mobilization, with more felled timber going to energy [1]. Sawn products would then drop from around 75% under business as usual conditions to around 60% for high mobilization scenarios.

The European forest industries recognized the importance of developing innovative forest-based products with higher added value to meet societal demands for materials, energy, employment, and environmental protection [2]. According to the National Research Agenda for the Swedish forest-based sector, developing and producing forest products with higher added value is an important strategic goal [3]. It is generally understood that shifting from high volume production of low-value goods to selective production of higher-value goods will increase the contribution to local and national economies from both limited resources of forest land and sustainably harvested forest biomass. However, the knowledge on specific ways to achieve this goal is incomplete. Whilst the production and export of sawnwood and paper products has increased steadily over the last few years, the future market of paper and wood products is uncertain, since it may be affected by biomass availability factors. The availability and utilization potential of forest biomass depends on the annual increment in forest volume and the annual demand of stem wood for building and other applied industrial purposes. Using a 20-year forecast, Börjesson et al. [4], predicted a balance between the demand for round wood for pulp and saw logs and the annual increment in Swedish forests around 2020. It was estimated that the increment in European forests would exceed the demand for stem wood for industrial purposes in Europe.

An assessment of biomass availability and quality is an important approach towards understanding its utilization

potential in various sectors. There are already several publications and a number of scenarios that predict biomass potential with regard to bioenergy [5–7]. This review specifically presents a detailed assessment of Swedish forest biomass by evaluating its gross availability, quantity and conversion and utilization. The paper also highlights some aspects of biomass production and utilization in the Swedish agricultural sector. An overview of the Swedish forestry sector is also presented as the main contributor of biomass. The environmental considerations in biomass utilization and the future prospects for a sustainable biobased economy are discussed herein. The overall aim is to share the Swedish experience in forest biomass production and utilization with an international audience since this development is fairly well-known in Sweden.

Overview of Swedish Forest Sector

The first modern Forestry Act in Sweden was passed in 1903. At that time, the country's forests had substantially decreased. An important objective of the Forestry Act was to secure the supply of wood for the future. A measure of how forestry has succeeded is that between 1950 and today, the standing volume has increased by 200%, from 1 to 3 billion cubic meters. The forest standing stock in Sweden has nearly doubled over the last century. Currently, the average growth rate of Swedish forests is 5.1 cubic meters $\text{ha}^{-1} \text{year}^{-1}$ [8]. A number of studies have suggested that changes in management practices can lead to substantial (> 50%) increases in forest growth, which would increase the long-term future potential of biomass harvest [9, 10]. Forestry and forest products have long been a key resource for the Swedish economy [11], supported by regular updates of national forest inventories since the original publication in 1923 [12]. As a result, Sweden has a unique set of long-term data describing the forest resource on regional as well as national bases. This is further enhanced with a long tradition of analyzing the consequences of different management practices [13] and well developed tools for modeling forest growth [14]. In addition, Sweden is well suited for analyzing the climate mitigation effects of active forest management in the boreal region.

In Sweden alone, forests cover 70% of the country's area, with around 87 billion trees. There is now twice as much timber in Sweden as there was 90 years ago. About 1% of Sweden's forest is felled annually [13], and for every tree harvested, at least two new trees are planted. The substitution effect of Swedish forest industry products is equivalent to Sweden's annual carbon dioxide emissions. Since the Swedish Forestry Act was updated in 1993, environmental and production targets in forestry have been brought in line with each other. Sweden's forest industry has reduced its

emissions by over 60% since 2005 and uses almost no fossil fuels in its processes, as 96% of the heating energy used by the forest industry is bioenergy. Of the country's total greenhouse gas (GHG) emissions, the forest industry accounts for around 1%. Electricity consumption in the forest industry is around 20 TWh per year, which is just over 15% of Sweden's total electricity consumption [13].

The forest sector (including wood industry and pulp and paper industry) contributes about 5% to Swedish GDP [15]. As the world's third largest exporter of forest products, Sweden exports 90% of pulp and paper products and about 70% of sawn timber products. The export value in 2018 was SEK 145 billion with SEK 15.4 billion of total investment, and almost 80% of the products were exported [16]. Every year, Sweden invests SEK 2 billion in forest research at universities, colleges and institutes. Forest industry companies also invest annually SEK 2.3 billion in their own research. According to the Swedish Forest Industries Federation [16], its members constitute 50 pulp and paper mills, 120 sawmills and 40 companies closely connected to the production of pulp, paper or timber goods. In terms of volumes, Swedish forest industries produced about 12 million tons of pulp (of which 4.3 million tons are market pulp), 11.3 million tons of paper and 18.3 million cubic meters of sawn timber in 2018 [16].

The Swedish forest ownership is distributed into six classes. Almost half of forest is owned by individual farmers, another 25% is privately owned limited companies, and the rest 25% forest is distributed between state-owned limited companies (14%), other private owners (6%), the state (3%) and other public owners (2%). Scots pine and Norway spruce are the two dominant tree species growing in Sweden, comprising 39% and 42% respectively of the total forest volume, with the remaining 19% comprising broad-leaved species. In terms of annual production, approximately 45% (around 40 million cubic meters) becomes timber. This in turn becomes furniture, construction timber, boards and planks, and other wood products. About 40–45% (i.e. 35 million cubic meters) becomes pulpwood from which newspapers, packaging and

other paper products are made, whilst just under 10% (i.e. 8–9 million cubic meters) becomes biofuel, which is then used for electricity and heating.

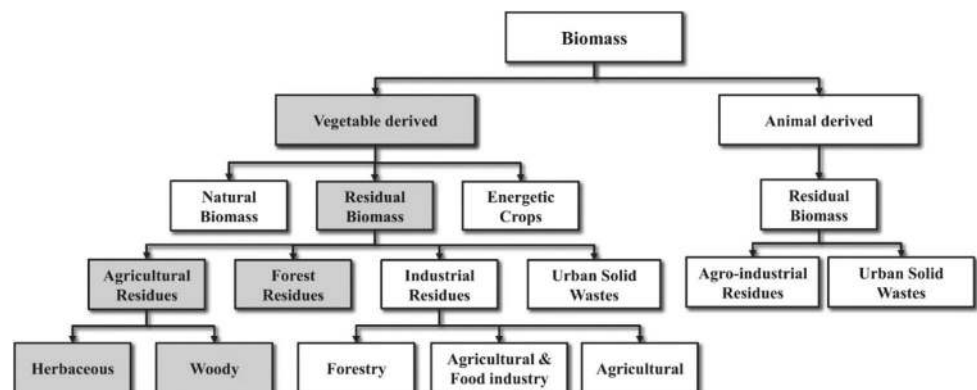
The Swedish forest sector continues to pursue growth in the world's bioeconomy sector by research and development. Based on the Swedish forest research agenda [17], the priorities of the forest sector include:

- Maintaining the competitiveness of existing production facilities in order to maintain profitability, but also to finance the development of new bio-based products and processes;
- Increasing the availability of forest raw materials whilst maintaining sustainable forestry;
- Developing new bio-based products to replace today's fossil-based materials and products;
- Stimulating an increase in industrial timber constructions to achieve more sustainable buildings;
- Increasing international research cooperation, since the market is international.

Biomass in Sweden

The classification of biomass is essential in understanding different biomass types and situations. In general, biomass can be classified based on its origin, characteristics, composition and disposal methods [18]. Roberts et al. [7] classified biomass into different categories as shown in Fig. 1. Based on the origin, biomass can be classified into vegetable and animal derived biomass. Vegetable biomass can be sub-classified into natural, residual and energy biomass. Natural and energy biomass are virgin crops while residual biomass are further classified into forest, agricultural, industrial and municipal solid wastes. Increasing urban population and activities are responsible for the generation of industrial processing residues, municipal solid waste, and other urban discards. This section discusses the

Fig. 1 Biomass classification based on the origin [7]



natural forest biomass available in Sweden. The potential of Swedish agricultural sector is also briefly discussed.

Forest Biomass Availability

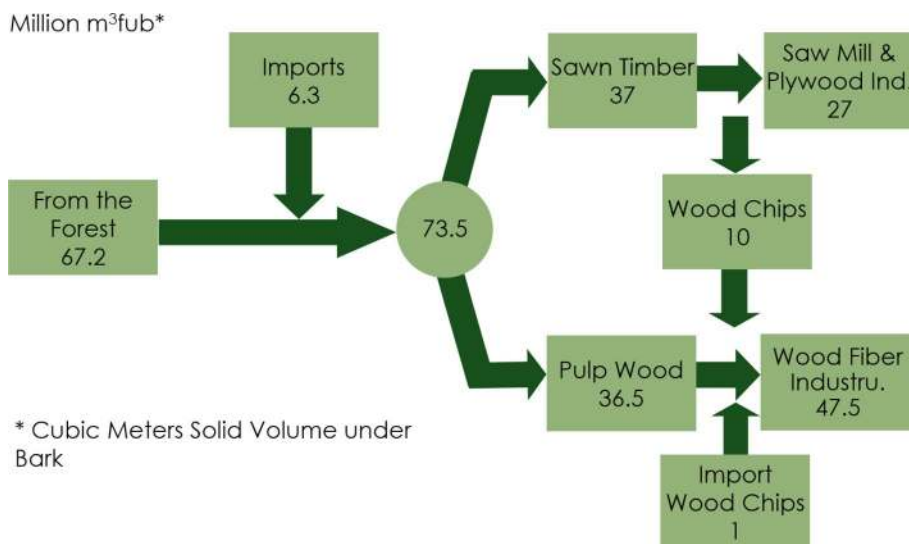
Forest biomass availability depends on adequate economic and environmental conditions. Depending on the climate and crop-harvesting schedule, there can be seasonal constraints on biomass availability and significant annual variability in resource yields at a local level [19]. Adverse environmental conditions can have significant negative or positive impacts on annual resource availability. The total forest biomass in Sweden is increasing and is currently about 1750 million tons dry weight [20]. This represents the theoretical potential which may be different from realizable biomass potential. Given the steady growth in the demand for bio-based products, Sweden has invested significantly in biomass availability and supply security. Different processes are used to assess forest biomass availability. Some assessments ascertain biomass potential for a sustainable utilization, as well as the social, environmental, and economic impacts associated with resources production and use [19]. Other assessments analyze biomass potential using detailed forest inventory database while considering the constraints that reduce biomass availability for different mobilization scenarios [21]. Biomass resource assessments guide industry development strategies and support decision-making processes. Generally, attempts are made for developing biomass functions from stem diameter and height, which give better coefficient of determination for stem biomass prediction [5]. Statistical analysis revealed that diameter at breast height was the best predictor for the aboveground biomass.

The Swedish forest sector is defined to include wood resources as well as the use of these resources, i.e., forest products and energy uses of wood. According to Sandberg

et al. [22], forest products include all the primary wood products manufactured in the forest processing sectors (sawnwood, wood-based panels, paper and paperboard) and the main inputs or partly processed products used in other sectors (round wood, pulpwood, wood residues, recovered paper). Secondary or value added forest products (such as wooden doors, window frames and furniture) are not covered, although trends in these markets have been taken into consideration. Traditionally, forest supplies the sawn timber and pulpwood used by the forest industries. In the Swedish forest sector, raw material imports are fed into the primary processing level. The total biomass comprising sawn timber and pulpwood is then used by sawmill and the wood fiber industries to manufacture products for both national and international markets as presented in Fig. 2.

The forest not only supplies the sawnwood and pulpwood, it also provides forest thinning, logging residues and forest undergrowth used in the bioenergy sector. These resources may have some seasonal variability, but typically remain at consistent levels in most areas. They also tend to be more spatially concentrated [19]. The bioenergy sector also utilizes all sorts of wastes and side streams from saw logs and pulpwood. These residues are used in producing biofuel for heat and electricity generation, as well as producing pellets for heating and liquid biofuels for transport. Besides fuel production, there has been a growing interest in the development of other biorefineries to develop economically viable products and chemicals as substitutes to those produced in traditional oil refineries [23]. The side streams of pulp and paper products are utilized in these biorefineries in producing value-added chemicals and consumer products. Figure 3 shows the conversion pathway for the Swedish forest biomass. Apart from forest biomass, agricultural and energy crops represent alternative primary renewable biomass sources in Sweden. Energy crops are important biomass

Fig. 2 Wood flow for the forest industries 2017 [16]



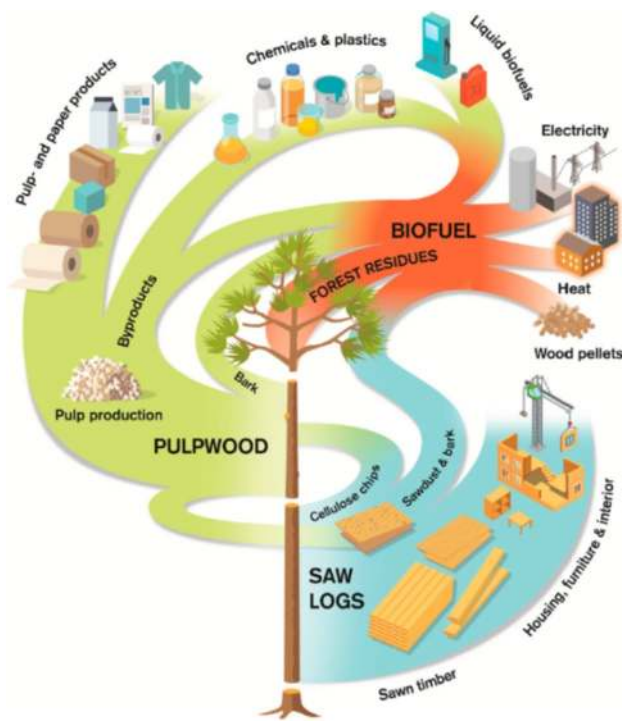


Fig. 3 Forest biomass conversion [24]

specifically grown for bioenergy, and they are mostly cultivated in transitioned grasslands. Energy crops mostly include fast growing tree species such as *Salix* and *Populus* with rotation periods of 5–10 years. After cultivation, the entire biomass is used for energy generation. It should be noted that the bioenergy sector is not part of this review and will not be analyzed further in the following sections.

Agricultural Sector

The Swedish agricultural sector has the potential to contribute more to the development of a sustainable economy. This is achieved not only by the production of sustainable food crops but also utilizing side streams of agri-industries and underutilized land for biomaterial sourcing. In the last 20 years, the agricultural area has decreased its contribution to the gross domestic product (GDP) from approximately 1% to less than 0.3% such that the national contribution to GDP was SEK 4.4 million in 2016. The total arable land used in Sweden today is about 2.5 million acres, whilst a further 450,000 acres are used as pastureland [25]. Other than food crops, there are small areas for farming energy crops, however not to a great extent. Profitability might be one reason for the small volumes, since there are vast volumes of forest biomass byproducts, organic waste and also cereals that are used for conversion to energy streams. The future prospects of using materials from the agricultural sector highly depend on the available land for non-food crops.

The available material streams are dependent on the overall profitability and today, most of the materials are used in energy related streams.

Biomass Utilization in Sweden

As already discussed, Swedish forest biomass has a wide variety of uses, including traditional industrial uses for sawnwood products and pulp and paper production, as well as in the energy sector for combined heat and electricity generation. In addition, it is of considerable interest for the development of continuous largescale production of advanced liquid and gaseous biofuels [26]. Thus, Swedish forest biomass represents an important component within the available local, national and regional supply of renewable raw materials. The following sections discuss the Swedish forest industries, their products and market potentials.

Sawmills

Swedish sawmills have a long history and have played a significant role in the economic development of the country. The history of Swedish sawmills can be divided in two phases. The first phase was from 1850 to 1900, which began with the establishment of sawmills, and then it became a leading export sector by the end of the nineteenth century. The second phase was from 1900 to 1990, comprising constant developments and overcoming several crises including the World Wars, the oil crisis of the 1970s, and competition from pulp and paper industrial developments [27]. The future of sawmilling in Sweden depends on some important factors necessary to meet the global demands and business opportunities. Some of these include: increasing the size of the firm, skill and knowledge transfer, encouraging the use of wood in ‘green building’, product diversification or value added strategy, improved technology and mechanization [28–30].

Currently, Sweden is the largest softwood exporter in Europe with 12.4 million m³ exports out of 18.2 million m³ production in 2018. Table 1 shows the national production, import and export data of sawnwood in Sweden compared with Europe from 2014 to 2018. In Sweden, the production of sawn softwood has been fairly stable during this period, showing a slight improvement from 17.4 million m³ (2014) to 18.2 million m³ (2018). The exports of sawn softwood also increased from 12.1 million m³ to 12.4 million m³ within the same period. In the European market, the export of sawnwood increased steadily from 71.1 million m³ in 2014 to 88.1 million m³ in 2018 [26]. In Sweden, the domestic consumption of sawn softwood showed

Table 1 Production, import and export of sawnwood in Sweden compared with Europe [32]

Sawnwood	Value (m ³)	Region	2014	2015	2016	2017	2018
Sawnwood, coniferous	Production	Sweden	17,400,000	18,074,000	18,260,000	18,309,000	18,273,000
		Europe	133,452,732	136,331,722	141,906,718	149,109,630	153,871,383
	Import	Sweden	408,980	409,648	429,257	485,766	463,532
		Europe	32,906,321	33,310,193	34,698,263	37,436,315	38,464,805
	Export	Sweden	12,131,470	12,827,600	12,996,000	13,110,654	12,437,000
		Europe	71,170,766	73,845,714	78,953,745	84,782,337	88,181,215
Sawnwood, non-coniferous all	Production	Sweden	100,000	100,000	97,000	97,000	100,000
		Europe	13,913,555	13,972,830	14,527,078	15,917,149	16,263,426
	Import	Sweden	27,720	28,436	42,709	45,983	45,750
		Europe	4,518,772	4,592,643	4,787,586	4,886,176	4,915,209
	Export	Sweden	9270	4732	19,301	42,715	26,556
		Europe	6,911,202	7,787,892	7,951,709	8,685,840	8,777,696

very significant improvement due to rapid development of engineered wood products and increased demands of such products, especially cross-laminated timber (CLT) in the building sector [31]. On the other hand, sawn hardwood had steady or slightly decreased production, while import and export figures during the period have been markedly variable (Table 1). Sweden is the single largest market for the Swedish sawmills, with usage in 2017 rising to 5.5

million m³ [31]. This demand has been driven by a strong housing activity, which climbed to its highest level since the early 1990s and was estimated to increase by 10% to 70,000 units in 2017. Also, the demands in retrofitting and maintenance activity has remained at a healthy level [16].

Statistics from sawmill database [33] showed that the production of sawn timber in Sweden was undertaken by 265 active sawmills, generating SEK 26.7 billion in revenue.

Fig. 4 Different side streams in sawmill operations

Sawmilling operations also generate various side streams (Fig. 4), which can be used as secondary raw materials for different industrial processes. These side streams can be grouped into five categories, including bark, cellulose chips (C-chips), planer chips, sawdust and uneven dry chips. C-chips are directly delivered to the pulping industries, while the other categories are mostly used for energy generation, either at sawmill or delivered to municipal incineration plants.

Pulp and Paper Mills

Sweden is dominant within the global pulp and paper market, as it is the world’s second largest exporter of pulp and paper products. Thus, the pulp and paper sector is of key importance for the Swedish economy, and provides employment for more than 120,000 people including those indirectly involved in services, maintenance and other related activities. However, the production volumes have been shrinking since 2000 and are today at historically low levels [34]. There are several reasons that have contributed to this result, mainly the rising market competition and to a lesser extent, the reduced production of newspaper due to the digitalization of the media market. Since the Swedish pulp and paper industries are more focused in packaging

products and are less specialized in newspaper production, the total production has only reduced by 12% over the last ten years [35]. It should not be forgotten that the pulp and paper industry is very conservative and it is more focused on protecting existing business structures [36]. Therefore, the needed transition towards biorefinery concepts to provide access in new value chains and transformations to more efficient milling technologies are slower than they should be to maintain competitiveness [37–39]. This fact has to be attributed to the high capital and energy intensive character of the sector along with the close dependence on energy prices, which make it difficult to realize industrial changes in a short timeframe [40].

A thorough overview of inventories of the Swedish pulp and paper sector during the past 20 years has been published by the Swedish Forest Industries Federation [16]. During this period (1994–2018), Sweden’s pulp production expanded from 3.3 to 4.3 million tons, while paper production expanded from 9.2 to 10.3 million tons. Bleached sulfate softwood was the major product in 2018 (68%) followed by other chemical pulp (22%) and mechanical and semi-chemical pulp (10%) (Fig. 5). The packaging products were the dominant paper products in 2018 (paperboard and packaging with 29% and corrugated materials with 22%) (Fig. 6). A continuous increase was

Fig. 5 Sweden’s pulp production 2018 [16]

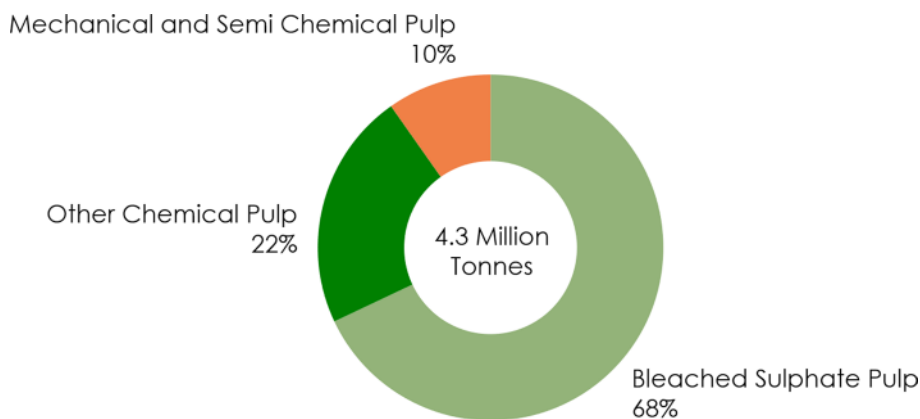
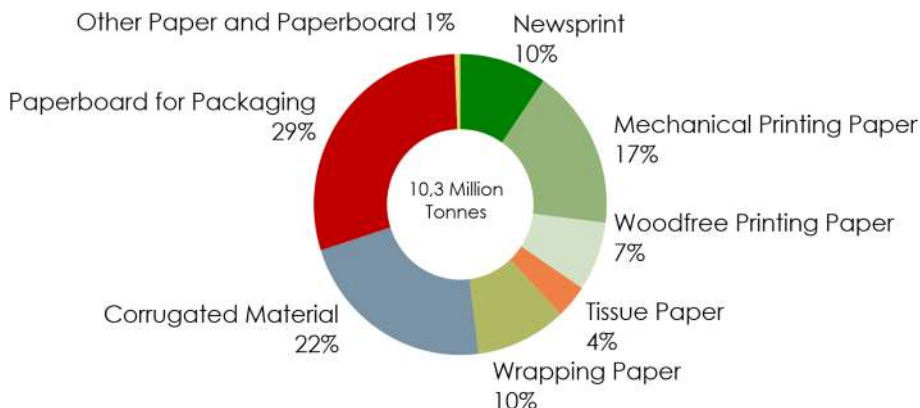


Fig. 6 Sweden’s paper production 2018 [16]



noted for paper production, despite an interruption in 2013 due to closures of paper mills. For both pulp and paper production, the domestic deliveries have remained broadly unchanged, and most of the growth in capacity has being used for exports.

Overall, the pulp and paper exports increased from 2.9 to 3.6 million tons and from 7.7 to 9.2 million tons, respectively for the years 1994 and 2018 [16]. The major part of these exports was to EU countries (76% for both cases, e.g. 2.4 million tons pulp and 6.3 million tons paper and paperboard products). Bleached sulfate softwood pulp had the highest market share of 84% in 2018 while the export

share of the different paper and paperboard products ranged from 61 to 96%. The other pulp types (mechanical and semi-chemical pulp, other chemical pulp) are dedicated to domestic use, and their export share was very low (10–16%). The production of chemical and semi-chemical wood pulp in Europe has been fairly stable during the last five years. In the European market, exports of chemical wood pulp was 14.6 million tons in 2018 compared to 14.2 million tons in 2017, whilst imports decreased from 18.2 million tons in 2017 to 17.8 million tons in 2018 [26]. More details on pulp and paper production, including exports and imports in

Table 2 Production, export and import of market pulp in Sweden compared with Europe [32]

Pulp type	Value (tons)	Region	2014	2015	2016	2017	2018
Chemical wood pulp	Production	Sweden	7,736,025	7,788,999	8,009,011	8,248,125	8,112,323
		Europe	31,081,263	31,025,705	31,025,705	33,058,774	33,288,221
	Export	Sweden	2,675,026	2,693,248	2,638,951	2,675,026	2,867,323
		Europe	13,233,566	12,805,494	13,968,964	14,186,430	14,554,232
	Import	Sweden	338,130	352,514	365,943	340,739	322,019
		Europe	17,186,705	17,387,275	18,005,863	18,156,442	17,829,169
Dissolving wood pulp	Production	Sweden	540,000	535,000	532,750	503,000	478,000
		Europe	1,873,286	1,839,910	2,110,222	2,154,215	2,142,662
	Export	Sweden	532,450	360,672	272,776	287,400	287,000
		Europe	1,532,767	1,556,315	1,246,348	1,332,556	1,287,383
	Import	Sweden	16,170	13,431	14,219	22,746	21,592
		Europe	932,219	780,586	743,176	750,904	716,539
Mechanical wood pulp	Production	Sweden	3,010,346	3,050,118	3,033,473	3,142,601	3,142,601
		Europe	10,656,919	11,178,108	11,587,485	11,554,798	11,554,798
	Export	Sweden	31,240	55,716	60,230	68,204	68,204
		Europe	387,997	351,343	285,463	331,387	331,387
	Import	Sweden	10,260	10,513	18,910	24,747	24,747
		Europe	247,247	277,801	236,587	275,818	275,818
Pulp from fibers other than wood	Production	Sweden	0	0	0	0	0
		Europe	1,393,252	1,349,084	926,954	706,551	645,752
	Export	Sweden	90	28	0	19	91
		Europe	227,212	159,343	140,367	134,472	113,659
	Import	Sweden	12,990	14,000	13,595	13,349	14,517
		Europe	240,611	180,551	166,838	156,565	157,231
Recovered fiber pulp	Production	Sweden	250,000	250,000	250,000	250,000	250,000
		Europe	23,898,360	24,665,786	21,691,489	21,844,094	22,124,320
	Export	Sweden	90	163	561	802	169
		Europe	134,400	153,109	148,871	147,754	195,787
	Import	Sweden	4450	3215	3592	3762	5010
		Europe	177,214	79,150	88,511	98,900	113,204
Semi-chemical wood pulp	Production	Sweden	244,654	247,882	246,527	255,399	255,399
		Europe	244,654	1,824,645	1,921,587	1,898,882	1,898,882
	Export	Sweden	1,987,949	207,276	279,029	315,972	315,972
		Europe	215,290	859,661	1,083,419	1,187,336	1,187,336
	Import	Sweden	832,435	18,311	137,483	179,913	179,913
		Europe	26,690	579,159	676,495	753,013	753,013

Table 3 Production, export and import of paper and paper based products in Sweden compared with Europe [32]

Paper and paper products	Value (tons)	Region	2014	2015	2016	2017	2018
Carton board	Production	Sweden	2,609,000	2,620,000	2,867,000	2,954,000	2,972,000
		Europe	10,767,202	11,310,452	11,800,368	12,027,475	12,079,603
	Export	Sweden	2,480,000	2,690,027	2,884,209	3,117,000	2,940,000
		Europe	9,601,455	10,164,015	10,530,765	11,445,710	11,620,858
	Import	Sweden	124,790	137,008	142,630	119,540	99,472
		Europe	7,474,874	7,656,377	7,917,173	8,122,485	8,262,956
Printing and writing papers	Production	Sweden	3,067,000	3,067,000	2,593,999	2,577,010	2,509,999
		Europe	31,691,061	31,691,061	29,215,140	29,065,773	28,457,260
	Export	Sweden	3,121,050	3,121,050	2,683,309	2,441,000	2,331,000
		Europe	27,709,445	27,709,445	26,396,982	25,892,746	25,598,018
	Import	Sweden	281,750	281,750	269,197	325,186	275,725
		Europe	20,829,681	20,829,681	19,902,406	19,642,514	19,132,049
Recovered paper	Production	Sweden	1,161,000	1,210,000	1,159,000	1,155,000	1,148,000
		Europe	60,155,113	60,619,063	60,945,979	60,992,982	60,609,628
	Export	Sweden	453,030	466,672	501,434	452,063	430,773
		Europe	23,068,810	24,322,200	24,749,439	25,244,565	24,453,911
	Import	Sweden	700,500	604,254	634,919	579,520	702,170
		Europe	14,490,314	14,922,913	15,469,982	16,214,392	16,086,023
Wrapping papers	Production	Sweden	1,010,000	1,060,000	1,033,000	1,038,000	1,014,000
		Europe	5,486,303	5,745,029	5,666,116	5,800,048	5,850,015
	Export	Sweden	962,000	1,139,281	1,059,000	940,000	914,000
		Europe	5,135,892	5,540,751	5,651,348	5,635,237	5,958,016
	Import	Sweden	103,450	79,367	55,723	50,667	50,580
		Europe	4,212,649	4,265,264	4,355,937	4,599,236	4,752,655
Other paper and paperboard (not elsewhere specified)	Production	Sweden	60,000	61,000	53,000	71,000	63,000
		Europe	3,953,889	3,939,889	4,091,309	4,531,730	4,549,772
	Export	Sweden	15,040	18,213	18,233	2,614	2,355
		Europe	636,120	819,749	849,157	866,745	716,252
	Import	Sweden	6,030	7,478	27,011	2,236	1,502
		Europe	771,765	779,254	915,045	849,748	828,689
Newsprint	Production	Sweden	1,258,000	1,197,000	1,016,000	1,011,000	977,000
		Europe	9,174,552	8,444,360	8,305,841	7,831,952	7,584,686
	Export	Sweden	909,670	889,877	768,735	846,000	790,000
		Europe	6,156,845	5,838,463	5,771,530	5,743,283	5,389,206
	Import	Sweden	32,230	25,658	54,035	58,042	51,702
		Europe	4,505,790	4,302,995	4,272,432	4,079,995	3,856,586

Sweden compared with Europe between 2014 and 2018 can be seen in Tables 2 and 3.

Regarding the structure of pulp production, the 5 largest mills (out of the 18 operating pulp mills) accounted for 57% of the capacity (i.e. 2.3 million tons) in 2018, and mainly produced sulfate pulp. The total capacity for pulp was 4.3 million tons, while Sweden's total pulp capacity for the year 2018 was 12 million tons [16]. For paper production, the 14 largest mills (out of a total of 38) accounted for 54% of the capacity (i.e. 6.2 million tons) in 2018. The total paper capacity for 2018 was 11.3 million tons. In terms of mill size, the "400,000 tons plus" category typically accounted

for those that produce newsprint, writing and printing paper, paper for the production of corrugated board and packaging paper. Of the "100,000 tons and under" category, half the mills produce soft tissue paper, but the rest also includes mills that produce packaging paper. There are a few large actors dominating the sector, with the four largest companies Holmen, SCA, Södra and Stora Enso together representing 64% of the production of pulp and 60% of paper in Sweden.

The pulp and paper industries in Sweden rely on local forest based raw materials. The total stocks of coniferous logs, pulpwood and wood chips were estimated to about 6.4 million m³ f ub (cubic metre solid volume excl. bark) in

2017. This is a decline by 19% compared with 2016 due to a decrease of 34% of all assortments of pulpwood stocks. The total stocks of pulpwood amounted to 2.9 million m³ f ub in 2016, of which 1.88 million m³ f ub were mixed coniferous, 0.47 million m³ f ub spruce and 0.9 million m³ f ub broadleaved species [16]. The stock volumes of wood chips (0.8 million m³ f ub) were also decreased by 10% in 2017 compared to 2016. According to the data, paper production is mainly based on chemical pulp (50%), then mechanical and semi-chemical pulp (28%), recovered paper pulp (9%), and filler and pigments (13%). The sustainability of paper companies in Sweden is partly due to paper recovery. In 2018, approximately 1.2 million tons of different recovered paper grades (e.g. newspapers and periodicals, corrugated containers, high grades, other) were used in the production of different paper products [16]. Imports of recovered paper have decreased while exports have slightly increased since 2010, but the volumes are low for both cases and below 0.5 million tons. However, paper recycling has almost reached its limits in Sweden and it was 80% for packaging, 95% for newspapers and 65% for office paper in 2017 [16].

The competitiveness of the Swedish pulp and paper sector has been boosted historically by a combination of favoring factors, such as low energy prices, skilled work force, access to high quality forest raw materials, efficient transportation infrastructure and efficient product and process development [41, 42]. Pulp and paper companies in Sweden are pioneers in efficiency as the recovery of waste (defined as recovery of material and energy plus other utilization as percentage of total amount of waste) from production processes in the period 2001–2018 has been constantly around or more than 90%. Also, since the beginning of 1980s, pulp and paper mills have reduced the organic materials they release into the water system by 90% and have reduced the sulfur compounds they release into the air by 98% [43, 44]. However, the increased competition from the global market along with regulations on pollutants and emissions, and increasing electricity prices have forced the industry to intensify its sustainability efforts in the last twenty years, mainly towards investments in energy efficiency, and production of biofuels and other renewable electricity [45–47]. As a result, the pulp and paper mills are today climate neutral and the sector is one of the major renewable energy producers in Sweden [48, 49]. The Swedish pulp and paper industry has the lowest carbon emissions per ton of product in the world followed by Norway, Finland and Canada [50]. This is acknowledgment to the environmental legislation and Sweden's energy and climate policy [40].

Construction and Furniture

The construction sector (wood panels, solid wood, etc.), represented by the building and housing industry, consumes

about 70% of volume of sawn timber annually in Sweden, in the form of framework material, moulded construction timber, form work, windows, stairs, impregnated wood, etc. The joinery and furniture industries consume a much smaller portion (ca. 20%) of volume of sawn timber but the added value of this portion of refined wood products is 15–20 times higher [16]. Given that 70% of the sawn volume is exported, it is thus evident that the value of the products going to the construction sector is currently very low and the manufacture within the country of solid wood products with a high added value is also low. Today, there is an increasing production of timber houses in Sweden as well as an increased degree of renovation of old buildings, due to a combination of favoring factors such as modern building regulations, allowing for multi-storey timber buildings, lower costs of building with wood compared to constructions using other materials, growing environmental awareness and governmental policies [51]. Currently Kulturhus, a 19-storey cultural centre and hotel is being built in Skellefteå by the Swedish firm White Arkitekter. The 76 metres structure is proposed to be the tallest wooden building in the Nordic countries [52]. White Arkitekter plans to realize the building using two types of hybrid construction system, rather than an entirely timber frame. The first brings together wood and steel, while the other pairs wooden modules with concrete slabs [52].

In detail, timber houses represent around 90% of newly constructed single-family housing [53, 54]. This trend is expected to increase the need of new wooden furniture and joinery products and to create opportunities for increased cooperation between the building industry and the furniture and joinery industries. The machining industry in Sweden would be forced to satisfy the modern building processes that require more refined timber in the form of components and systems in order to achieve a high productivity [22].

The Swedish timber house industry in 2017 consisted of 527 companies with 6062 employees, 32 of which accounted for 75% of the market share of assembly-ready houses [54]. The production value was around SEK 15.0 billion in 2016. The total exports of prefabricated timber houses declined by 21% and amounted to SEK 575 million in 2016 compared to 2015, and there was an increase of imports by 11%. Besides sawn timber, the construction, furniture and joinery industries are supplied with materials from the wood-based panel industry. According to Statistics Sweden, this industry together with the parquet industry consisted of 74 companies with 1530 employees in 2015. The output accounted for approximately SEK 3.9 billion and value added amounted to SEK 1.1 billion. There was an overall rise in production of wood-based panels by 8% to 626,000 m³ in 2015 compared to 2014. Exports of wood-based panels such as HDF/MDF and plywood declined while imports increased from 2014 to 2018. In contrast, the export and import of wood based

panels in the European market increased during this period. The Swedish furniture industry in 2016 comprised 2290 companies, of which 1445 are companies with null employees. Total numbers of employees were 13,376. In 2015 the total production value of furniture amounted to SEK 24.5 billion. Exports of furniture rose by 1% to SEK 15.9 billion in 2016 compared to 2015. Norway is the main market of export, whilst other EU countries are also important. Total imports of furniture increased by 3% to SEK 16.6 billion in 2016 compared to 2015 [55]. Swedish imports were mainly from Poland, Norway and the EU countries. More details on the production, exports and imports of the Swedish

wood-based panel industry compared with Europe in the years 2014 to 2018 can be seen in Table 4.

In recent years, the cost of wood raw material, energy and chemicals has negatively affected the wood-based panel industry in Sweden. The industry will continue to face growing competition for wood from the renewable energy sector [51]. Much of Sweden is facing a housing shortage, primarily in its metropolitan regions. Sweden has one of the highest levels of urbanization in the EU. Housing construction has continued to increase, but remains well below new construction needs. To meet this demand, Swedish wood-based panel industries have continued to invest and develop new wood and cellulose-based products, such as bioplastics

Table 4 Production, export and import of wood-based panels in Sweden compared with Europe [32]

Wood based panels	Value (m ³)	Region	2014	2015	2016	2017	2018
Hardboard	Production	Sweden	0	0	0	0	0
		Europe	3,950,939	3,826,589	4,003,920	4,147,215	4,085,855
	Export	Sweden	3160	5154	4506	4088	4502
		Europe	3,025,398	2,998,853	2,983,668	3,137,478	3,077,012
	Import	Sweden	74,110	75,912	75,724	75,767	72,571
		Europe	2,288,632	2,296,073	2,447,583	2,646,395	2,777,011
MDF/HDF	Production	Sweden	0	0	0	0	0
		Europe	13,366,319	14,912,175	16,110,190	17,366,139	17,825,338
	Export	Sweden	58,330	47,099	42,182	39,227	39,176
		Europe	7,935,065	8,447,006	8,963,345	9,554,343	9,772,434
	Import	Sweden	222,990	225,296	218,831	210,684	225,222
		Europe	6,557,705	6,325,566	6,457,142	6,837,703	7,349,227
OSB	Production	Sweden	0	0	0	0	0
		Europe	5,972,507	7,292,078	8,498,002	9,009,650	9,379,072
	Export	Sweden	1230	1645	3959	5277	5676
		Europe	3,743,499	4,048,906	4,780,731	5,265,979	5,126,208
	Import	Sweden	122,370	123,289	158,064	158,032	173,066
		Europe	3,335,765	3,292,965	3,528,064	3,985,551	3,973,343
Particleboard	Production	Sweden	494,000	600,000	550,000	550,000	550,000
		Europe	41,221,423	42,141,954	42,417,405	44,000,160	45,036,532
	Export	Sweden	88,700	60,031	80,719	97,283	88,843
		Europe	14,308,105	14,684,844	15,363,200	16,428,707	15,950,745
	Import	Sweden	427,640	427,489	413,952	456,558	464,338
		Europe	11,651,703	11,812,064	12,352,278	13,159,674	13,173,419
Plywood	Production	Sweden	82,000	60,000	60,000	85,000	85,000
		Europe	8,279,646	8,375,523	8,772,743	9,786,426	9,823,923
	Export	Sweden	31,160	24,447	22,470	21,415	22,927
		Europe	6,248,770	6,517,498	7,088,530	7,411,564	7,621,096
	Import	Sweden	162,910	149,650	174,720	206,485	223,054
		Europe	7,144,216	7,180,879	7,503,526	7,774,507	8,071,428
Other fiberboard	Production	Sweden	0	0	0	0	0
		Europe	3,009,481	2,902,253	3,222,878	3,679,957	3,713,269
	Export	Sweden	8950	4092	9537	14,988	11,768
		Europe	1,747,560	1,783,779	1,743,605	1,660,058	1,538,636
	Import	Sweden	33,260	29,973	33,834	40,476	36,652
		Europe	1,527,938	1,586,506	1,794,968	1,948,315	2,019,047

and biocomposites. There has been significant investment in research and development by the big players in the industries. For instance, Martinsons opened a new CLT line in 2017. Södra is also investing in its first CLT facility at Värö with an initial production of 5000 m³ from 2019 onwards. Stora Enso has also invested in production of CLT in Gruvön to start production in 2019. In addition, Stora Enso recently started a new biocomposite plant which produces DuraSense™. This product is a wood-fibre biocomposite that offers the mouldability of plastics and the strength and sustainability of wood. The development of the product results to approximately 80% reduction in carbon dioxide footprint over conventional products. These developments indicate that there is a strong trend in increased wood processing with the manufacturing of building elements.

Biorefineries

The use of biomass as raw materials for biochemical production has been motivated by realizing a reduction in fossil carbon dioxide emissions, ensuring security in energy supply, and a desire to revitalize rural areas [56]. The Swedish biorefinery sector has been expanding in products manufacturing over the last decade. The recent climb in fossil oil prices, customer preference for eco-friendly products, population growth and limited supplies of non-renewable resources have opened up new channels of opportunity for biobased products and polymers [57]. One of Europe's premier biorefineries based on wood as a raw materials is located in Domsjö, Sweden, which utilizes renewable wood raw materials and converts them into various green products for a diverse range of uses [58]. These products are then refined by secondary biorefinery companies, which are subsequently used to produce textiles, medicine, foodstuffs and other consumable materials. The Biorefinery Demo Plant in Örnsköldsvik, Sweden, has all the necessary competence and equipment to convert biomass into various final products, e.g. carbohydrates, lignin, proteins, enzymes, chemicals, material and ethanol [59]. There are several other small and large biorefinery companies in Sweden with dedicated and integrated production facilities. These companies are active in research and development, product development, consulting or manufacturing within the included business segments of the chemical industry, with a total of about 33,000 employees. Today, the chemical industry is providing modern materials and enabling technical solutions in virtually all sectors of the economy [60].

There is a growing demand for biochemical products in Sweden but more biorefineries will only have a small effect on the availability and pricing of wood products and feedstock [61]. The replacement of fossil oil with biomass as raw material for fuel and chemical production has been the driving force for the development of biorefinery complexes

[56]. However, the cost of biochemical production exceeds that of petrochemical production. As a consequence, the new biobased products must be proven to perform at least as good as the conventional products and have a lower environmental impact [57]. In biorefining, different biomass materials can be converted to different classes of biochemical products through jointly applied conversion technologies. The Swedish biorefinery concept focuses on utilizing renewable forest biomass as much as possible for producing a variety of products, i.e. making more out of the tree [58]. Forest residues are also important sources of raw materials for the biochemical industry. Forest residues consists not only of cellulose and hemicellulose, which can be fermented to useful molecules, but also of lignin. One challenge is therefore to find ways of using not only the cellulose and hemicellulose, but also the lignin to realize valuable compounds from the biorefinery [62]. There is a potential to significantly increase the use of forest residues in Sweden, compared to current levels. However, a certain share must be recycled to the forest to avoid degradation of soil organic carbon and nutrients [62]. The bark of stem and foliage are the main carriers of micro nutrients while the foliage is the main carrier of macro nutrients [63]. These are vital ecosystem residues and should meet certain ecological restrictions in order to achieve sustainable biomass production and utilization as a renewable material [63]. Ecological balance and ecosystem productivity depend on the composition and the amount of extracted biomass. Therefore, the environmental sustainability of using forest residues as raw material in a biorefinery is still under consideration.

Swedish biochemical industries accounted for approximately 17% of Swedish exports (including pharmaceutical and mineral oil products). The main biobased products are obtained from biomass processing into basic products like starch, oil, and cellulose. In addition, chemicals such as lactic acid and amino acids are produced and used in the food industry. Other commercial biobased products include adhesives, cleaning compounds, detergents, dielectric fluids, dyes, hydraulic fluids, inks, lubricants, packaging materials, paints and coatings, paper and box board, plastic fillers, polymers, solvents, and sorbents [56]. Currently, most companies that have integrated facilities for biochemical production focus on development and manufacturing of biofuels. Domsjö Fabriker, which produces celluloses used for manufacturing textiles (viscose) is Sweden's largest producer of biogas. Some of the companies develop and manufacture chemicals or materials (e.g., Arizona Chemicals and Organoclic) and some focus on process development (e.g., Bioendev and the process for torrefaction and Värmlandsmetanol and the process for producing methanol from wood) [60].

The Swedish pharmaceutical products and reagents companies account for almost half of the employment in

the chemical industry, but only contain about 20% of the number of companies. The chemical industry is dominated by a limited number of large companies. More than half of the companies produce chemical products, yet these companies are generally rather small and their combined share of employees is only about 25% [60]. Regarding the structure, the Swedish biochemical industry is characterized by a small number of large companies and corporate groups, yet roughly corresponds to 80% of total employment in 2014. Compared to previous years, there has been a slight change mainly due to the fact that the largest companies have decreased their share of employment more than the industry average [60]. Companies in the business segment consist of larger exporting companies (Lantmännen Agroetanol, SEKAB, Arizona Chemicals, Domsjö Fabriker, etc.) and smaller companies focused on development and demonstration of biorefinery technologies (e.g., Taurus Energy, Ligno-boost Demo). Most of the companies engage in research and development and/or product development, usually in cooperation with other companies [60].

Environmental Considerations

Due to the current opinion that the provision of wood as raw material does not cause high GHG-emissions, wood and wood products are commonly claimed as carbon neutral. Usually, the carbon dioxide that is released when trees are felled is absorbed by surrounding forests, which makes the wood material climate neutral [64]. This opinion is manifested with the consideration that all removed biomass from sustainably managed forests will be sequestered again in the future [65]. Similarly, an increase in tree biomass means an increase in carbon sequestration. Due to the absorption of carbon dioxide, forests are generally regarded as carbon dioxide sinks. They can also be regarded as carbon dioxide neutral, since the carbon dioxide absorbed from the start of their life cycle is released when the forests are harvested [64]. Wood products from forest biomass will continue to act as significant carbon sinks, which can be extended until the wood decays or is burned. It also implies that an increased use of wood will help to counteract the release of carbon dioxide at felling [64]. However, the issue of carbon neutrality remains a controversial point [66] and may be further confused through issues such as land use changes [67]. Carbon neutrality can play a significant role in GHG emissions, as has been identified by the Intergovernmental Panel on Climate Change (IPCC) [68], given that levels of atmospheric GHGs are at their highest for some 800,000 years [69]. Sustainable biomass utilization is beneficial for global climate due to carbon neutrality and issues resulting from emissions [70]. Carbon accounting allows for tracking of carbon between the environment and products and resulting

carbon trading has been applied within the bioenergy sector [69]. The environment could also be referred to as a social-ecological system [71, 72] as “there are neither natural or pristine systems without people nor social systems without nature. Social and ecological systems are not just linked but truly interconnected and co-evolving across spatial and temporal scales” [73]. The interconnection of ecological and social systems is also present in life cycle impact assessment (LCIA) methodology, where the areas of protection in endpoint-modelling typically cover both ecological and social values.

To meet the challenges that climate change presents, there has to be a shift to sustainable biomass production and increased interest in promoting a circular bioeconomy. Sustainable biomass production from forest ecosystems is affected by the terrain, ecological parameters, forest management, and the landscape’s heterogeneity and conservation [70]. The spatial approach using Geographic Information System and Remote Sensing assists the creation of ecological and sustainable framework in biomass harvesting procedures from forest ecosystems. This opens new horizons for research in spatial limitations which have to be considered to ensure the preservation of an ecosystem [55]. The positive relationship between sustainable forest management, growth and carbon dioxide uptake can be illustrated by developments in Sweden over the last 100 years, where silviculture has been focused on long-term sustainable production [64]. Sustainable forest biomass utilization needs to be combined with silviculture through effective forest management in order to achieve the environmental goals [70]. With current management practices, the Swedish forest will continue to provide an annual climate benefit that corresponds to a 60 million ton reduction in carbon dioxide emissions. Most of this climate gains will come from replacing fossil fuel with renewable forest biomass. The positive climate mitigation effect is estimated to be greater than the temporary gains that could be achieved by reducing felling in order to build up the carbon sinks in forests and forest soil [64].

There has been an upsurge in the use of timber in construction through the development of advanced construction products. The use of timber in modern buildings has been shown to benefit from encapsulated carbon within the building structure, effectively locking it in use for decades. This has been effectively shown in a range of recently constructed buildings. The replacement of conventional building materials such as concrete, metal and other fossil-derived materials with wood products where applicable, will result in greater carbon gains [64]. For every cubic meter of timber harvested for use as a wood product, approximately 470 kg of carbon dioxide emissions is eliminated.

Conclusion and Future Prospects

From the outset, it is evident that the available biomass in Sweden can be utilized to provide a sustainable supply of materials (i.e. timber, pulp, paper and paper products, chemicals, biocomposites, and other construction materials) for present and future needs. The sustainable management of forest biomass will continue to provide opportunities for economic growth and productivity, as well as promote a carbon neutral bioeconomy. There are a range of business opportunities that can be based on the Swedish forest sector, which can be summarized into the following thematic groups:

- Processing of primary products into solid wood, and its supply into well-established products (e.g. construction, furniture)
- Processing of secondary products, primarily in the pulp and paper industry
- Use of solid timber and residuals within the biorefineries and bioenergy sectors
- Increased extraction of forest residuals within existing markets or meeting new demands

These categories represent the main business areas that can be served by the Swedish forest sector. With increased environmental awareness and the desire to live in a more carbon neutral society, the use of bio-based materials is seen as a means of lowering the human impact on resources. Whilst Sweden has an abundant forest supply, there is a fixed maximum that can be harvested per year in order to maintain a sustainable resource. Therefore, increased demands from each business sector will increase the political strain on the biomass resources, which are dependent upon market forces and associated prices. Forest products are normally allocated on the basis of the users' willingness to pay (and hence prices meeting needs and demands). National economic policies can impact the willingness to pay for specific sectors both positively and negatively depending on the specific policy implemented. This national demand can significantly affect international forest trade and supply. In order to develop a sustainable bioeconomy, several actions need to be considered. These include; establishing policies that can drive transitions into a biobased economy, improving alignment with bioeconomic objectives, establishing competences to address the bioeconomic potential and improving collaborations across sectors.

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